Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: August 26, 1971

to: Distribution

B71 08036

from: J. J. O'Connor

subject: On the Problem of Continuous Television During Rover Traverses - Case 320

ABSTRACT

Among the advantages of continuous TV coverage we have increased TV duration, increased lurain coverage and real-time determination of the Rover track. Of course, it is understood that image motion and jitter due to movement of the unstabilized TV camera may limit its usefulness. The disadvantages include increased electrical power consumption and a requirement to gimbal mount and steer the high gain antenna. Most of this memorandum is devoted to this last point.

It is concluded that manual steering by an earth-based teleoperator is not possible due to the 3 second time delay, and that a monopulse tracking scheme would be a major redesign. Gyroscope stabilization cannot be ruled out but it appears to have many problems. A pendulum system is not recommended because it converts Rover dynamics into pointing errors, but a novel use of an electrically locked pendulum to account for general lurain slopes is pointed out.

The system that appears to have most promise is a two gimbal system with an earth sensor operating in the visible spectrum. It offers the possibility of truly continuous coverage, minimum astronaut interface and elimination of the optical sight and omni antenna system.

(NASA-CR-121544) ON THE PROBLEM OF CONTINUOUS TELEVISION DURING ROVER TRAVERSES, CASE 320 (Bellcomm, Inc.) 18 p

N79-72716

Unclas
00/32 12110

FF No. 602(A)

(PAGES)

CR 121544

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

I. INTRODUCTION

This memorandum describes some of the general considerations which we uncovered in studying the continuous TV problem over the last several months. It is the path we took in deciding to examine the earth sensor approach in some detail. The trade-offs we made should not be considered as definitive and certainly new information is available from the now accomplished Apollo 15 mission. We decided to publish this preliminary investigation of the problem because it may be of some help to the people who are now actively engaged in deriving a solution to the problem.

II. THE PROBLEM

The Apollo television camera is mounted on the front of the Lunar Roving Vehicle (LRV) in a set of gimbals which allow azimuth angles from +170° to -170° and elevation angles from +85° to -45°. The pointing of the camera, as well as its focus, is under earth-based control via the Ground Control Television Assembly (GCTA). When the LRV is stationary, the TV picture can be received on the earth if an astronaut (manually) points the High Gain Antenna (HGA) towards the earth; he uses an optical sight to position the 2° image of the earth within the ±2.5° HGA beamwidth (1 dB points).

The present situation of receiving the TV picture only while the LRV is stationary has several disadvantages. In examining the pros and cons of continuous TV coverage, we will use as typical the parameters of recent planning of the Apollo 15 LRV traverses.

III. THE CASE FOR CONTINUOUS TV COVERAGE

A. Increased TV Duration

An analysis[1] of the three Apollo 15 traverses shows approximately 8 hours of station time to 4 hours of LRV movement. Thus, continuous coverage would give a 50 percent increase in TV time.

B. Increased Lurain Coverage

With some 14 science stops in the total traversed distance of 36 km, only 10 percent of the lurain area within 125 m of the traverse locus would be seen (and recorded) on the earth without continuous TV coverage.

C. Variable Aspect of Lunar Formations

To the extent that there is scientific value in the TV coverage itself, as distinct from its mapping function to locate the several science sites, the panoramas at the sites have the disadvantage of a single location of the TV camera. Panoramas made from several points along the traverse would enhance the estimation of the size, shape, distance, and relative orientation of the lunar formations.

D. Real-Time Determination of the LRV Track

With the present situation, the earth-based scientists can determine if the planned science site has been reached only after the LRV is stopped, the astronaut has pointed the antenna towards the earth, and a TV panorama has been received. With continuous TV coverage, the earth-based scientists would have an opportunity to track the LRV during the traverse to confirm the arrival at the planned science site or to redirect the astronauts, if necessary, via the continuous voice link.

E. Improved PR Potential

While the 8 hours of coverage at the science sites will contain certain highlights, (for example, the initial panorama at each site and some of the more energetic astronaut movements) the bulk of the time spent in collecting and documenting samples, and checking and aligning the LRV systems may prove to be boring to a general audience. Coverage during the traverse, however, would have the advantage of an ever-changing scene. Further, such "live" coverage may present the viewer with the sensation of actually riding the LRV on the moon, the best example of this was the roller coaster scene in the first Cinerama movie. It should be mentioned directly that both of these points may prove to be negative, as discussed in the next section.

IV. THE CASE AGAINST CONTINUOUS TV COVERAGE

A. Image Motion and Jitter

By image motion we mean rapid changes of the field of view caused, mainly, by the LRV attitude changes. While each frame might be a clear image of the scene, rapid sequences of frames which have very little overlap due to the changes in the camera pointing angle will be uncomfortable and disorienting to the viewer. By image jitter we mean the small but rapid changes in the camera position caused, mainly, by the translational changes of the LRV chassis. While the field of view might remain constant, the small-amplitude motion of the image will tend to smear the contrast levels within the image; this will tend to blur the small detail and sharp outlines. The viewer will have the impression that the image is out of focus.

Both of these problems of image motion and jitter raise questions about the PR potential of continuous TV coverage; in fact, they could prove serious enough to negate the other advantages of continuous coverage. Therefore, a later section of this report will discuss the possibilities of an early evaluation of these two problems.

B. Gyro-Stabilization and Shock Mounting

The image motion problem could be solved by mounting the TV camera on a gyro-stabilized platform, and the image jitter problem could be solved by the proper shock mounting of this platform. The weight, development time and expense problems associated with this approach exclude it from any further consideration herein.

C. Real-Time Mission Planning

In the real-time determination of the LRV track, as discussed in section III.D, there will be a temptation to request deviations from the pre-planned traverse to take advantage of unexpected items of interest or to improve upon a poor choice of science sites. This would tend to negate much of the pre-mission planning, time-line analyses and consumables allocations.

D. Electrical Power Consumption

The power consumption of the Lunar Communication Relay Unit (LCRU) goes from 60 w to 90 w during TV transmission, and the LCRU power budget is completely allocated However, there is a power connection to the LRV power supply. The Apollo 15 plan called for the use of LRV power to the LCRU for LM ascent TV coverage, which occurred after the LRV mission was completed. It would have to be determined if an earlier operation of this power interconnect would be compatible with normal operation of all the LRV systems.

E. Reception of TV Transmission

It appears that TV coverage during LRV motion requires a steerable high gain antenna to position its $\pm 2.5°$ beamwidth towards the 2° earth image. After examining alternates to this requirement, this report will examine in some detail the problems associated with a steerable antenna.

V. EVALUATION OF IMAGE QUALITY

As mentioned previously, the degradation of the TV image due to motion and jitter should be evaluated. Either or both of the following suggestions may be useful in this evaluation.

A. Earth-Based LRV Experiment

The observations of images generated by a TV camera mounted on an earth-based vehicle would give some insight into the image degradation problem. Of course, this test would be more pertinent the closer the vehicle simulates the LRV dynamics and the closer the terrain simulates the lunar surface. But the test should not be deferred to get the best possible vehicle on the best possible terrain. The results from almost any kind of a test would be useful to scope the problem.

B. Apollo 15 Motion Pictures

The five minute sequence of motion pictures taken from the moving LRV was very impressive, but it may tend to over sell continuous TV, which will not be as good. Besides the resolution and contrast advantages, the movie camera has a rapid shutter speed relative to its frame rate. This gives a sharp image for each frame with the LRV motion only showing up frame by frame; in the terminology of section IV.A, we would say that the motion picture contains the expected image motion (for the particular lurain sample traversed), but it does not contain the image jitter as would be seen on the continually scanned TV image. Perhaps the image motion of this sequence could be applied to a TV camera which is viewing an equivalent scene, for example, an enlarged print of a frame taken from the motion picture sequence, to determine the degradation caused by image jitter. This may seem like a tedious approach and the Apollo 15 sample available to us may not be typical, but it should be noted that this is a sample taken from an actual LRV operated in the lunar environment.

VI. IS A STEERABLE ANTENNA REALLY NECESSARY

The narrow beamwidth of the high gain antenna requires steerability during LRV motion, but let us first examine if the use of this antenna can be avoided. There are two possibilities involving the use of the omni or low gain antenna: one is direct use of the omni and the other is use of the LM as a relay.

A. Direct Use of Omni Antenna

The omni antenna has a beamwidth of, say, ±30°, which is adequate to handle all reasonable LRV attitude angles. It would be necessary to point the omni generally towards the earth at the start of the traverse and then proceed without further concern. The problem, however, is signal power. The gain of the omni at the 30° points is +6 dB which is 15 dB down from the +21 dB gain of the high gain antenna. Even using the 210' dish at Goldstone* instead of the 85' dish recovers only 8 dB. There is still a loss of 7 dB and the current circuit margins are inadequate for operation at this level.

B. Use of Omni Antenna with LM Relay

The Lunar Module (LM) has adequate transmitted power for TV reception on the earth and its proximity to the LRV would overcome the low power levels of the omni antenna. But there are three problems associated with this approach. First, there is the line-of-sight between the LM and LRV, but some coverage would be available. For example, on at least one of the three traverses of the Apollo 15 mission about 50 percent of the traverse is within the visual coverage from the LM. Second, there is the lurain reflection problem; this is difficult to evaluate as the multiple

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*Reference 2 examines the 210' coverage for Apollo 16.

path reflections may cause complete degradation of the TV image. Third, there is the frequency incompatibility as listed in the table below. The 2265.5 mHz LCRU transmitter frequency cannot be received by the 2101.8 mHz LM receiver. It is for this reason that this approach was not suggested even on an experimental basis.

TABLE I

S BAND FREQUENCIES (mHz)

	Uplink	Downlink
LM	2101.8	2282.5
LCRU	2101.8	2265.5

VII. STEERING THE HIGH GAIN ANTENNA

We therefore accept the requirement that the high gain antenna must be steerable. Of course, the present configuration is manually steerable through a ball joint with the astronaut applying the turning torque via a boom handle. But we need a technique for automatic and continuous steering of the antenna during the LRV traverse. Two approachs present themselves: linear actuators and gimbal rings.

A. Linear Actuators

The possibility of using the existing ball joint and minimizing the swiveled mass make linear actuators attractive, but two problems preclude this approach. The large attitude angles possible with the LRV, say ±30° in two axes, would lead to a large ratio of maximum to minimum length of the linear actuators. Also there are no off-the-shelf linear actuators in this class of small size, light weight and rapid response; indeed, they would present quite a development effort.

B. Gimbal Rings

While the use of gimbal rings will increase the swiveled mass, they represent proven technology. The size and strength of the gimbals can be designed to the specific antenna requirements, and the torquing motors are available in many sizes and types. It should be noted that while there are three LRV attitude angles, two gimbals will suffice if they correct for the LRV pitch and roll attitude; the third angle, the attitude of the antenna about its own axis, does not need to be controlled. Some pointing systems, such as azimuth and elevation, could require three gimbals.

In tracking the earth, it should be noted that it is the LRV chassis which is moving not the earth. That is, the antenna would remain pointed toward the earth if it could be isolated from chassis movement. LRV attitude disturbances could be reduced by low friction bearings in the gimbal system. To reduce the effects of translational motions, however, the c.g. of the swiveled mass would have to be at the center of the gimbal system. This balanced antenna system would add weight to the system, either by requiring large gimbals to centrally support the present antenna, or by the addition of a counter weight to balance the antenna offset from the present gimbal point (ball joint). The weight impact of this approach could be reduced by using as a counter weight some item already carried to the moon, e.g., a battery or a tool, or by use of something already there, e.g., lunar soil.

The alternative approach to a balanced antenna system would have to counteract all the LRV accelerations applied to the offset c.g. of the swiveled mass. However, this approach would allow the use of such items as stepping motors and self-locking gear trains. The electrical loads would be largely transient with a low duty cycle (during steps) and the system could be completely turned off while the LRV is stationary.

The trade-off between balanced and unbalanced gimbal systems should be examined in great detail and the choice may be determined by details of the hardware configurations.

VIII. POINTING THE HIGH GAIN ANTENNA

We now examine the problem of pointing the steerable antenna towards the earth receiving antenna. There appears to be four possibilities: manual scanning, monopulse tracking, gyroscope stabilization, and earth sensing.

A. Manual Scanning

In this approach an earth-based operator would have control over the LRV antenna pitch and roll attitude via the continuous uplink voice channel. This operator would also be able to monitor the received TV signal strength. By commanding pitch and/or roll rates and noting the time of the maximum signal level, the operator could specify the proper antenna gimbal angles. Indeed, this scheme was proposed for the operation of an unmanned Rover (while it was stationary between steps of movement). The problem here is the delay time in the loop.[3] The propagation delay and the earth-equipment processing time give a loop delay of approximately 3 seconds and this is too long relative to the LRV attitude dynamics. It would lead to an unstable loop.

This scheme might still be viable if it produced TV reception during a greater part of the LRV traverse and the interruptions were of a momentary nature. Unfortunately this is not the case. In order to synchronize the video signals as generated on the LRV with those used in the commercial TV networks, the received signal is stored on a tape recorder, and then (via a variable length of tape loop) is transferred to a second tape recorder which is run in synchronization with the network signals. The loss of the received signal causes both of these video recorders to lose their raster and frame synchronization which could take 10 sec. to reestablish. (This adds up to 20 seconds because the first recorder must reestablish its synchronization before it can synchronize the second recorder.) There is an additional delay of up to 10 seconds in the synchronization of the magnetic disc used in the (sequential to parallel) color converter. Thus the momentary loss of signal can lead to a 30 second delay in the recovery of the TV picture. When we further consider delays in the manual reacquiring of the antenna, we are left with a very low duty cycle of TV reception, and on the whole, an unacceptable situation.

B. Monopulse Tracking

The earth-based antenna is sending a continuous rf signal to the LRV high gain antenna during the TV transmission. If the LRV antenna could track this signal, it would automatically be directed towards the earth receiving antenna. And this has been done before on the Apollo program; both the CSM high gain and the LM steerable antennas were converted into (sequential) monopulse tracking systems. The serendipity here was the method used to derive the circular polarization of the rf signal. The CSM antenna consisted of four horns and four dishes from which it was relatively easy to derive the right-left and up-down error signals for the steering servos. The LM antenna used four dipoles in front of a splash plate; it was only necessary to notch the splash plate into quadrants to derive the steering signals. Unfortunately, the LRV high gain antenna uses a more direct approach; it uses a coaxial feed into a helical wrap to generate the circularly polarized rf signal. With this arrangement there is no easy way to generate the two-dimensional error signals. There are, of course, other (and older) ways of designing a tracking radar--for example, conical scan--but these would so modify the high gain antenna that no further consideration will be given to them herein.

C. Gyroscope Stabilization

Inertial stabilization of the antenna axis is a possibility due to the slow rotation of the line of sight between the moon and the earth; this line of sight rotates 360° in 28 days or about 0.5°/hr. Since the receiving antenna can be any place within the earth image (due to the rotation of the earth about its own axis), we must consider the positioning of the entire 2° earth image within the ±2.5° antenna beamwidth. A centered image will move to the edge of the beam in (2.5 - 1)/0.5 or 3 hours. This in-beam pointing duration could be doubled to 6 hours if the initial positioning of the earth image were at the opposite edge of the beam.

This edge positioning of the earth image could be done as follows. Assuming that there is a manual alignment of the antenna towards the earth via an optical sight, we need a 2.5° reticle, that is, a circle within the sight which shows the limits of a ±2.5° cone around the optical (and antenna) axis. The question then is at which angle along this reticle should the earth image be positioned. This angle can be prelaunch calculated on the basis of the launch date and the coordinates of the landing site. Either the astronaut must be able to estimate local vertical, or the LRV must be brought to an almost horizontal attitude. Also a correction must be made for the indicated heading, read on the LRV NAV system. There are no severe requirements on the accuracy of this reticle angle since 90 percent of the in-beam duration is available for reticle angles within ±25° of the nominal value.

These in-beam pointing durations of 3 or 6 hours are compatible with the typical traverse durations of 2.5, 4.8 and 5.6 hours.[1] In fact, the present plans call for a manual pointing of the antenna at each science stop and the longest traverse time between stops is less than one hour (56 min.). However, we have not yet considered gyro drift. With a gyro drift rate as little as 0.1°/h, the in-beam pointing durations would be reduced by 0.1/0.5 or 20 percent. If the inertial rate of 0.5°/h could be completely accounted for and the in-beam pointing duration requirement was only one hour, the allowable gyro drift would be (2.5 - 1) or 1.5°/h. The compensation of the inertial rate would complicate the system in that it would have to be resolved onto the LRV pitch, yaw and roll axes; this complete coordinate conversion system makes the gyro stabilization concept unattractive.

A logical choice for the mounting of the gyro is on the antenna; it is the device which should have the fixed inertial orientation. This approach would, of course, increase the swiveled mass, enlarge the gimbal system, and complicate the power and signal flow across the gimbal points. A remote mounting of the gyro, say, on the LRV chassis, might reduce some of these problems, but it would introduce other problems, such as the mounting of resolvers on the gimbal points to measure and reproduce the angles measured between the gyro and the LRV chassis.

From the foregoing comments it appears that a gyro stabilized antenna is feasible, but it would require more detailed consideration to evaluate such parameters as a single two-degree of freedom gyro vs. two single degree of freedom gyros, gimbal mounted vs. remote mounted, etc. It does appear that a reasonably good gyro is necessary, and in order to get a small size, it will be expensive. It is these cost and weight trade-offs which cause us to proceed to the evaluation of an earth sensor.

D. Earth Sensing

There are several advantages in the use of an earth sensing device. It is completely automatic and does not require an earth-based teleoperator. It is not affected by the geometric libration of the moon which can cause the zenith angle of the earth to vary by ±8° in both latitude and longitude.[4] It is not subject to gyro-like drift. It is a null seeking system and its output is a direct measure of the desired quantity, namely, earth pointing errors. It is second only to the monopulse tracking system in this regard.

The earth sensor would be mounted on the gimballed antenna, parallel to the antenna axis. It would give a two dimensional measure of the position of the earth image either by four separate outputs or by two differential outputs, depending on the physical details of the sensor used. In either case, orthogonal signals would be available for up-down and left-right correction. These signals would be fed to the pitch and yaw gimbals, the motion of which would cause the signals to go to zero. It should be noted that no coordinate conversion is necessary and even orthogonality of the gimbal axes is not required because the error signals will only go to zero when the earth image is centered on the sensor. Any non-orthogonality of the gimbal axes (due to the orientation between the LRV and the earth) would only change the sensitivity of the servo loop. Sensitivity correction could be derived from the gimbal angles, but it probably will not be necessary for the expected gimbal angle range of ±30°.

One problem with an earth sensor is to keep it from responsing to the radiation from the sun. A program was written to calculate the sun-earth angle as seen from the moon as a function of the sun elevation angle at any specified lunar site. Assuming a minimum sun angle of 5° at LM landing and a minimum postlanding checkout time of four hours, the sun rate of 0.5 °/hr gives an initial sun angle of 7° for the start of the first traverse. With a maximum landing sun angle of 23° and a maximum stay time of 68 hours (less six hours for liftoff preparation) the final sun angle of 54° was used for the end of the last traverse. Table II gives these initial and final sun-earth angles for Apollo 16 and 17 sites; the Apollo 15 site and the alternate site for Apollo 17 are also shown for reference.

TABLE II

SUN TO EARTH ANGLE AS SEEN ON THE MOON

NAME	APOLLO #	LANDING DATE	SUN-EARTH ANGLE INITIAL	SUN-EARTH ANGLE FINAL
Hadley	15	7/30/71	90°	36°
Descartes	16	3/22/72	91°	44°
Alphonsus	17	12/14/72	77°	24°
Davy Rille	17 alt	12/14/72	84°	31°

It is seen in Table II that the minimum sun-earth angle is 24°. Therefore, there should be a sun shade to attenuate radiation 20° off the optical axis. This sun shade will probably take the form of baffles in the tube leading to the earth sensor. While this might require some care in the baffle design, it leaves a comfortable margin for transient errors without worrying about sun capture of the antenna pointing system. Still, the earth sensor must survive direct pointing towards the sun.

If the sun sensor operated in the infra-red region of the spectrum, the earth image would tend to be circular independent of the position of the sun. But the spectral irradiance (watts/cm^2/μ) in this spectral region would give less signal energy than that in the visible region.[5]

In the visible region, the image of the sun-illuminated earth is crescent shaped, and with a 20° sun-earth angle, only about 5 percent of earth image would be illuminated. Since the visible-region earth sensor will center on this crescent image and the earth receiving antenna could be on the far side of the earth, the antenna pointing error, or bias, could be as much as 2°. However, this is within the ±2.5 beamwidth of the high gain antenna.

At the other extreme of a 90° sun-earth angle (Table II) about half the earth image would be illuminated. The earth shine on the moon for this case is 2.8 lumens/m^2 while it is less than 0.2 lumens/m^2 for a 20° crescent. This presents an illumination range at least 14:1. This may exceed the dynamic range of an otherwise acceptable sensor. If so, the following three points should be considered: the entire range from 20° to 90° will not occur on any one mission (Table II) and a prelaunch adjustment might set an iris diaphragm to a mid-position; the astronauts could set the iris to a precalculated value before each EVA; and finally the iris could be automatically adjusted (an electric eye).

The earth shine numbers of the previous paragraph were taken from Reference 6 and are traceable back to a 1963 issue of that reference. This probably precludes an experimental basis for the numbers and better data should be available now. One should also be concerned about the effects of cloud cover. It would seem that a 20° crescent could have a fair probability of very low cloud cover for reasonably periods of time; this would further reduce the minimum level of earth shine.

Depending on the size and configuration of the earth sensor selected and the level of earth shine available, it may not be necessary to use an optical lens system. The earth sensor might be mounted in the base of a tube with baffles to exclude sun light. The manual pointing of the antenna (which may be necessary only once for the entire mission to establish initial alignment) may be done by sighting along the tube, by use of a gun sight attached to the tube, or by use of the AGC meter reading of received signal strength. It should be noted that this manual pointing is only to get within the capture range of the earth sensor; the system itself will proceed with its own fine alignment. This would seem to be ample justification to remove the telescope which is now present for manual alignment of the antenna at each science stop. This would help to offset the weight increase of the continuous coverage system.

A study was made of the dynamics of the servo loop for an earth sensor system.[7] It was found that the attitude angles and angular rates presented no difficulties and the main disturbances were caused by LRV accelerations acting on the c.g. offset of the swiveled mass. These effects could be greatly reduced by balancing the antenna, but such a system would tend to drift off axis when power is completely removed. An unbalanced system with mechanically locked bearings has the advantage of requiring no stand-by power.

IX. PENDULUM SYSTEM

One approach which we had not considered before accepting the earth sensor approach is the use of a pendulum for local vertical orientation coupled with a heading correction derived from the LRV Navigation System. A manual adjustment of the antenna ball joint would direct the antenna toward the earth, thereby establishing the initial vertical or zenith angle of the earth. The combination of the pendulum-supplied local vertical orientation and the elimination of the effects of heading changes via the azimuth drive unit would keep the antenna pointed toward the earth for any LRV attitude.

It should be noted that this system uses three gimbals: two on the pendulum support for local vertical and one between the pendulum shaft and antenna for heading corrections. Further this particular set of gimbals for azimuth and elevation leads to greater gimbal movement for the near-zenith earth orientation than would, say, two gimbals for pitch and roll angles.

It appears that the pendulum system would isolate the antenna from the dynamic attitude changes of the LRV and would counteract general lurain slopes. The real shortcoming, however, is that it would convert LRV accelerations into antenna pointing errors. By definition, the pendulum cannot be supported at its c.g. and any accelerations of the support point act as torques on the pendulum. For example, a 90° turn with a 100' radius at 10 km/hr would give a pointing error of 9.3° for 17 seconds. A braking deceleration of 0.15 lunar g's would give an error of 8.5° for 12 seconds, again assuming 10 km/hr. The system would restore itself after these maneuvers, but the coverage would not be 100 percent.

A novel use of the pendulum system occurred to us as follows. By studying the dynamics of the antenna pointing requirements (by a fairly complete simulation of the LRV dynamics and statistically described lurain roughness), we concluded that the three sigma pointing angle variations were comparable to the antenna beamwidth. We examined a non-steerable antenna,[4] but found that the 12° to 14° earth zenith angles would require azimuth correction for the LRV heading. (Of course, this is part of the pendulum system.) There was still the 10° to 20° of general slope to accommodate, and the prospect of having the astronauts stop the LRV for manual antenna pointing each time there was a general slope change looked too unattractive to pursue this approach further.

But now consider the following use of the pendulum system. The initial alignment would manually establish the proper elevation angle of the antenna, and the antenna azimuth would be driven from the LRV NAV system. But the pendulum would be (electrically) locked in position. This would eliminate the disturbing effects of the LRV translational accelerations but would directly couple in the LRV attitude changes as pointing errors, hopefully resulting in less than a beamwidth variation. When there is a general slope change and in the absence of LRV maneuvers, one of the astronauts would electrically unlock the pendulum (from a button on the control console) until the pendulum assumes a local vertical position, and then he would electrically lock it again.

This is a pretty far out scheme and is not recommended because it still does not give 100 percent coverage.

X. SUMMARY

With the Apollo 15 mission now behind us, we can see how its overall success may present PR difficulties in showing innovations for Apollo 16. Continuous TV coverage is one possibility, assuming that image motion and jitter do not negate any advantages.

The two concepts of real-time determination of LRV track and real-time mission planning seem to be irrelevant now. The preplanned traverses with specified science stops was a plan and nothing more than that. The inevitable increases in task times forced deviations from the plan, and the astronauts at the scene were accepted as the best judges of the locations to be used for science stops.

It appears that continuous coverage requires a steerable high gain antenna which is mounted in gimbal rings. Manual scanning is out because of the time delays in the loop. Monopulse tracking is out because of the complexity it would introduce. Gyro stabilization is probably an acceptable approach but it looks like it could get very complicated, expensive and heavy. While the earth sensor has some of the same drawbacks, a careful design with proven components and thoughtful trade-offs of various possibilities should lead to an optimum system.

As an illustration of the last point, consider an unbalanced gimbal system driven by stepping motors through irreversible gear trains. The response time and the torque levels should be designed such that the antenna remains locked to the earth image for the expected ranges of LRV attitude changes and acceleration inputs. Such a system would remain in lock without any power when the LRV is stationary, either at science stops or between EVA's. The astronauts would only have to (coarse) align it after LRV deployment. Given such a system, one might remove the omni system, since continuous voice link would be available via the high gain antenna. Removal of the omni antenna could give a weight saving to offset the weight increases of the continuous system and it might be possible to use the rf amplifiers of the omni system to increase the radiated power of the high gain antenna, thus effectively widening its beamwidth, or equivalently, reducing the pointing requirements.

There are no basic reasons why several of the discussed schemes would not work. The earth sensor system offers the possibility of truly continuous coverage, minimum astronaut interface and elimination of some other systems (optical sight and omni antenna). It must, however, survive the pressure of cost, weight and schedule.

XI. ACKNOWLEDGEMENT

The author wishes to thank W. W. Ennis, B. A. Gropper, J. W. Head, R. W. Newsome, and J. T. Raleigh for their many helpful discussions during the preparation of this memorandum. He also wishes to acknowledge the work of S. Kaufman in the dynamic analysis of pointing angle requirements and the work of I. Y. Bar-Itzhack and A. Heiber in demonstrating the servo design of the earth sensor system.

J. J. O'Connor

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Attachment
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